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Efficiency Evaluation of 4D CAD Model

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Abstract

4D CAD model topic is poorly analyzed in Lithuanian construction's sector and 4D CAD in practice is hardly used. Number of projects designed by using the 4D CAD model in Lithuania is minimal, only applied to complex multi-story buildings. Efficiency evaluation of 4D CAD model is practically unstudied in Lithuanian construction industry. Purpose of this article – to assess the efficiency of 4D CAD model. For the evaluation of efficiency there was made experiment simulating the construction process. The experiment showed that the use of 4D CAD model, with limited time resources, provide to access almost twice bigger efficiency. 4D information model consists of assumptions speed up to construction process. Also 4D CAD model averagely twice reduces the likelihood of mistakes and helps to detect and remove them quickly.

Keywords: BIM, 2D CAD, 3D CAD, 4D CAD eficiency.

1. Introduction

Information sharing, proper modeling is becoming increasingly important challenge for construction projects from the idea to hand over the key. Information sharing between different project participants helps to solve the problems and improve different skills. 4D CAD design can help to increase the effectiveness of communication and reduce the opportunity for all interested in the interpretation of the construction project participants.

Construction processes efficiency promotion was analyzed by many scientists. In accordance with the provision that one of the conditions for maintaining efficiency – time spent on decisions and material resources management on building site, Wang, Zhang, Chau, Anson [1] have researched 4D application for dynamic management for construction planning and resource utilization process. Maa, Shen, Zhang [2] analyzed application of 4D for dynamic site layout and management of construction projects. Jongeling, Olofsson [3] analyzed method for planning of work-flow by combining location-based scheduling and 4D CAD planning. Tantisevi, Akinci [4] concerned for automated generation of workspace requirements of mobile crane to avoid conflicts. Russell, Staub-French, Tran, Wong [5] introduced the use of 4D CAD visualization for high-rise building construction using linear scheduling. Mahalingam, Kashyap, Mahajan [6] evaluated the applicability of 4D CAD model construction design. Turkan, Bosche, Haas, Haas [7] more interested in building automated process monitoring using 4D planning and 3D design technologies. Ku, Taiebat [8] proved 3D, 4D, 5D CAD relevance and need for the construction industry by analyzing the design model for the U.S. construction industry.

4D CAD modeling topic is poorly analyzed in Lithuania and 4D CAD is almost unused in practice. Number of items designed by using the 4D model is minimal, only applied to multi-story buildings, such as the Vilnius city municipality

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buildings complex, the project was made by UAB "In Re". That company is one of the 4D CAD programs representative in Lithuania. 4D CAD evaluation of the efficiency was not practically analyzed in Lithuanian construction industry. A new approach to 4D benefits presented Liaudanskiene, Simanavičienė, Ustinovičius [9], who analyzed the possibility of the model to reduce safety problems, which determine not only the time but also financial losses in the construction process. The most critical material in finding innovative construction sector efficiency and assessment decisions have Migilinskas, Ustinovičius [10, 11], Popov, Juocevičius, Migilinskas, Ustinovičius, Mikalauskas [12]. These authors not only looked for ways to increase the efficiency of the use of computer technology in design, but also emphasized the need to use methods to determine which parts of the construction process and the process of influencing factors are most important.

Purpose of the research – to evaluate 4D CAD effectiveness.

2. Efficiency Evaluation of 4D CAD model

2.1. Experiment of 4D CAD performance evaluation. Experiment proceeding

Stage 1. As construction object was used Lego blocks model "Apple Tree House" (see Fig. 1). There was used a simplified model of a house, eliminating welfare elements (trees, shrubs, benches, basketball stand, and additional house elements (satellite antenna, outdoor lamp). Windows, doors, garage door components supplied to the participants fully completed, merging into a whole. House model consists of 330 Lego bricks.

Fig. 1. Lego „Aplle tree house"

For the experiment Lego block house was used for several reasons: the Lego blocks kits are known, easy to use and does not need additional time to become proficient in the use of little-known or difficult constructors. Lego blocks are convenient to imitate one of the main tools for construction – bricks. Lego blocks allow you to create a realistic view of the house. Blocks easily taken apart and assembled. Parts vary in size, color, shape and enable participants to distinguish them faster and easier to use as a construction element counterpart.

Stage 2. Design Software selection, 2D and 4D experiment task design. There was selected Autodesk Revit 2011 design software, allowing for 2D and 4D drawings.

Stage 3. Create 2D and 4D CAD "Apple tree house" model drawings (see Table 1). Graphic drawings were produced in the 40 hours.

Stage 4. Experiment participants selection. Participants were chosen from civil engineering third-course students. Arguments of selection: civil engineering knowledge and ability to understand and use graphical information contained in both 2D and 4D CAD format. To the experiment selected 28 participants. 28 experiment participants were randomly grouped in 2 to set up team-working environment. Groups of 14 participants were randomly grouped into 2 subgroups. Seven groups have got 2D CAD drawings and other 7 groups entered the 4D group and got 4D CAD drawings.

Stage 5. Performance of the experiment. For experiment participants delivered instruction about experiment: objective of the investigation, participants' role at the experiment, the task which will be performed. Experiment participants filled the application in a questionnaire indicating age, practical work experience in the area of construction, the planned experiment completion time. Participants are introduced to the CAD drawings for the experiment. 2D subset of participants: 2D CAD drawings (see Table 1). 4D subset of participants: 4D CAD building model construction drawings numbered at different stages: Lego house broken into 28 stages (see Table 1).

Table 1. 2D and 4D groups drawings list

2D CAD drawings	4D CAD drawings
First floor plan (1'st line)	4D construction stages (1 & 2)
First floor plan (7'th line)	4D construction stages (3 & 4)
Second floor plan (11'th line)	4D construction stages (5 & 6)
Second floor plan (eastside of the roof)	4D construction stages (7 & 8)
Roof plan	4D construction stages (9 & 10)
East elevation	4D construction stages (11 & 12)
West elevation	4D construction stages (13 & 14)
South elevation	4D construction stages (15 & 16)
North elevation	4D construction stages (17 & 18)
Section 2-2	4D construction stages (19 & 20)
Section 1-1	4D construction stages (21 & 22)
	4D construction stages (23 & 24)
	4D construction stages (25 & 26)
	4D construction stages (27 & 28)

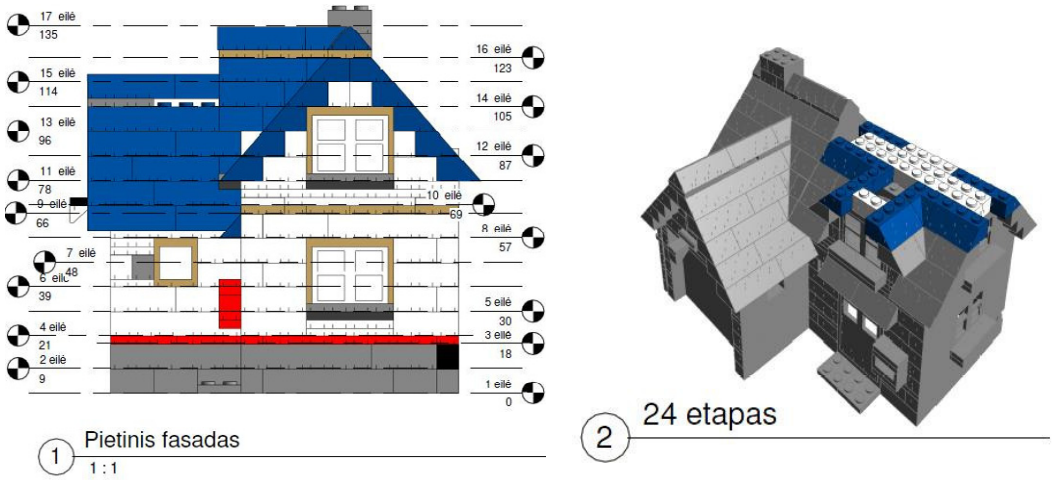

Fig. 2. Examples of Lego 2D group model and 4D group model drawings

Experiment task – the first phase: time 5 min. It is used for analyze drawings, to discuss the progress of the group. Experiment task – the second phase: "Apple tree house" construction. The second phase is to build a house for less time-consuming and making the less possible mistakes. The maximum time given for the construction of the model – 60 min. Experimental groups goal – to build construction projects, with limited time resources. These tools were used during the experiment:

- 4D CAD and 2D CAD drawing packages. Lego blocks kit of "Apple Tree House" (see Fig. 1).
- The stopwatch is used to record the time spent by each group spent time of building house.
- Camera to capture the course of the experiment. Experiment completion evaluation questionnaire, where marked completion time, number of mistakes made, the number of rebuilt blocks, task completion.

Stage 6. Experiment evaluation. Experimental evaluation criteria: Experiment participants' opinion about the time required for task completion. How much time needs house model construction, if it is built faster than the given time limit.

2.2. Results of efficiency evaluation of 4D CAD model

The participants of 4D group of experiment have completed averagely 99,1 percent of the object. The lowest object completion among this group's participants' is 98,8 percent. The best result according to the analysis criteria among 4D group participants – 99,4 percent.

Comparing the final building completion of 2D and 4D groups of participants, it can be concluded that the use of 4D model allowed under the limited period of time, achieve almost double productivity. Comparing experimental results of the two groups of participants identified that 4D group's participants have executed more construction extent in 48.6 percentages than 2 D.

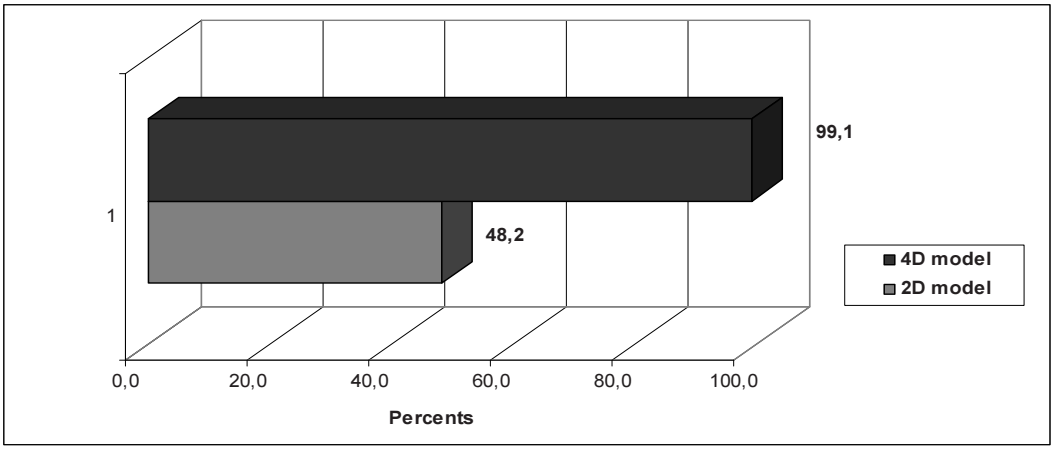

Fig. 3. Average percentage of model completed (%), using 4D and 2D models

During the experiment, participants were asked to identify potential construction period (see Fig. 4).

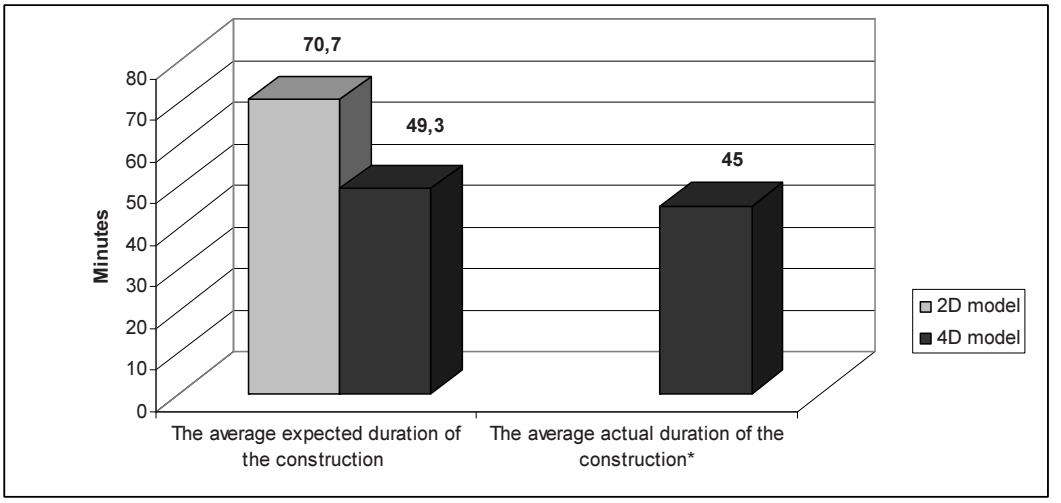

Fig. 4. The expected and actual construction duration of 2D and 4D groups.
*2D group participants did not end construction object in 100 percent

4D group's participants predicted lower time cost than the 2D group's participants. Minimum planned construction duration was 30 min., maximum – 60 min. The shortest predicted construction time among 2D group's participants was 50 min., the longest – 100 min. The projected construction duration comparison between different groups of participants shows that the participants using a 2D model are planning to spend more than half (62,1 percent) time cost of construction of the object than 4D.

During the experiment was evaluated how much time to complete construction object do groups of participants using different models need. During the experiment, none of 2D model using participants' couple have completed construction. Average time spent for construction object by participants' couples who used 4D model – 45 min. and that is more than 4 minutes less than predicted. Among 4D participants' construction object was completed within 36 min. The maximum time spent for the construction of an object – 59 min.

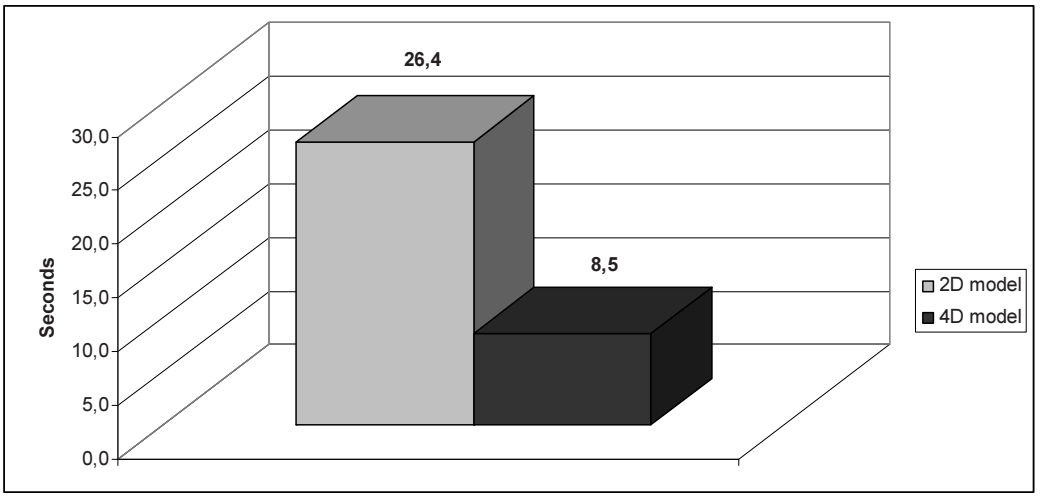

Fig. 5. Time expenses for one construction element (LEGO piece) (time in seconds)

When building object completion and time costs have been evaluated, then time costs were estimated according to seconds per one element of construction. The lowest time cost among 2D group participants' per construction element is 19,1 s., and the highest – 33 seconds. When assessing 4D group's results, the lowest time cost per item is 6,5 s., while the highest – 10,8 seconds. The average time required for the construction of one element using 2D model during the experiment was 24,8 s, and using 4D model – 8,2 s. To sum up the experimental results, it can be said that the use of 4D accelerates construction processes up to 3 times.

The number of unused blocks has been calculated during the construction process. Number of unused blocks of different experimental groups is presented in Fig. 6:

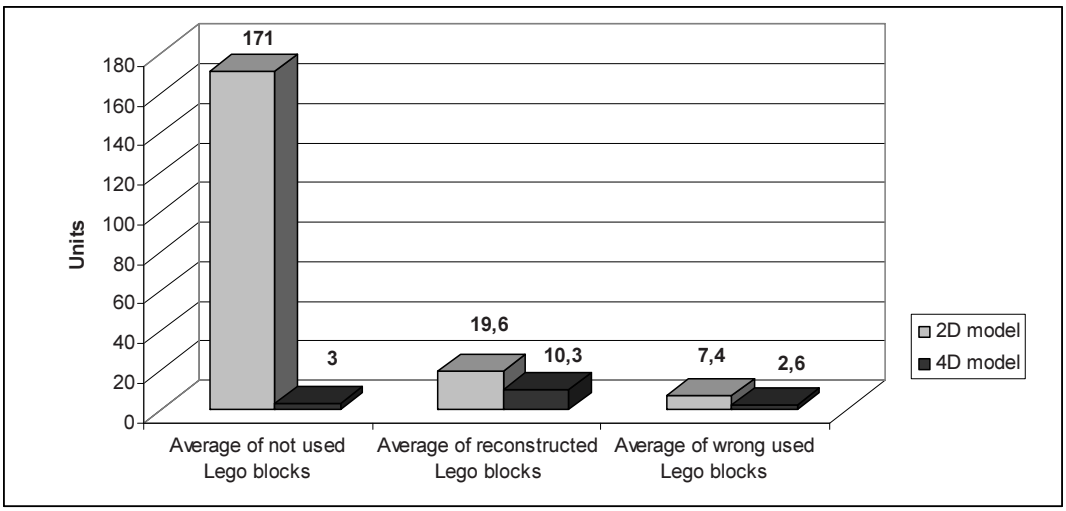

Fig. 6. Average number of times Lego pieces were reconstructed, wrong used, not used in 2D and 4D groups

The experiment showed that the 4D model information makes preconditions to speed up the construction process. The results showed that participants' couples who used the 4D model did not use only 3 building elements. Most of the unused building elements among 4D participants were 5 pcs., the lowest number of unused building elements – 1 pc.

The average of unused construction elements among 2D group's participants' is 171. The highest number of unused building elements is 221 pcs., the lowest – 142 pcs.

To sum up the research results, according to the number of unused building elements using different models, it can be concluded that the use of 4D model helps to complete construction object faster.

Errors that have been made and fixed during construction process were calculated during the research. Average number of rebuilt building elements using 2D and 4D models is presented in Figure 6. Among 2D group's participants' the lowest number of incorrectly used and rebuilt items is 9 pcs., highest – 34 pcs. Assessing the 4D group participants results according to the analysis criteria, it was observed that the lowest false used and rebuilt number of elements is 7 pc., highest – 13 pcs.

Comparing two groups of participants, it was noted that participants of 4D group construction process can reduce mistakes possibilities comparing with 2D group. 4D group had reconstructed 10,3 pieces, and 2D group reconstructed an average of 19,6 pieces. 4D groups reconstruction number is 90,3 percent less than the 2D groups. To summarize the experimental results it can be said that using 4D model it is possible to reduce the likelihood mistakes in construction process and help to detect and remove them faster.

The minimal number of incorrectly used pieces in 2D group is 1 pc., maximal – 18pcs. One group of 4D experiment participants did not make any mistakes when building a physical model. The biggest amount of mistakes in 4D group is 3 pcs, which was placed in wrong place. After experiment it could be said, that using 4D CAD drawings it is possible to reduce mistakes possibility almost three times.

During the experiment, participants were characterized by a subjective indication, which could affect the outcome results of the experiment – the practical work experience in the construction field. When there were evaluated relationship between the model completion and the construction experience, observed that the 2D group participant couples had longer practical experience in the construction field, and reached higher model finish. Participants with practical work experience in the construction field more than half a year built a 7,7 physical model, compared to participants without experience.

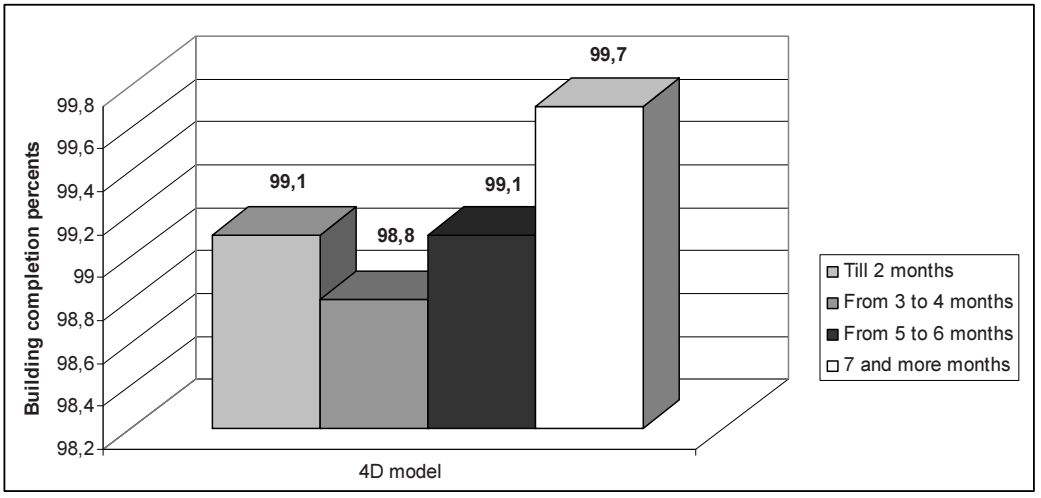

Fig. 7. Influence of work experience in constructions area on construction process in 4D group

Comparing the relationship between the amounts of work experience and model completion using 2D CAD and 4D CAD drawings, linear correlation method showed an existing statistical dependency. Analyzing 2D model experiment participants practical experience in construction sector and model completion relationship of linear correlation coefficient is 0,51, while for the 4D model participants it is 0,62 and confirms a direct connection.

3. Conclusions

Comparing 2D and 4D experiment groups participants' results of the final building completion, it can be concluded that the use of 4D model allowed under the limited resources of time, to achieve almost twice bigger efficiency. Comparing two

groups experiment results, the 4D group was able to construct 48,6% more of the physical model compared to 2D group. To summarize the experimental results it can be said that by using 4D model it is possible to shorten construction time by 1/3. The experiment showed that using 4D CAD model supplied information, construction process can go faster. Summarizing the experiment results by the number of unused building elements using different models, it can be concluded that the use of 4D model helps to complete the construction of the object much faster. Comparing two groups' participants' results, it was noted that participants of 4D construction process can reduce mistake possibilities comparing with 2D group. 4D group had reconstructed 10,3 pieces, and 2D group reconstructed averagely 19,6 pieces. In summary, 4D CAD model usage can twice reduce mistakes in construction process and help to detect and remove them faster. Comparing the relationship between the existing labor practices and completion of the model construction using 2D and 4D models, linear correlation method showed an existing statistical dependency. Analyzing 2D model experiment participants practical experience in construction sector and model completion relationship of linear correlation coefficient is 0,51, while for the 4D model participants it is 0,62 and confirms a direct connection.

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